Permeable Reactive Barrier
Remediation of Chlorinated Solvents in Groundwater

Introduction

Naval Facilities Engineering Service Center (NFESC) continues its commitment to environmental excellence by demonstrating new and innovative remediation technologies, such as the permeable reactive barrier (PRB) or treatment wall technology (Figure 1). The former Naval Air Station (NAS) Moffett Field in Mountain View, California, has extensive groundwater contamination with chlorinated solvents, including trichloroethene (TCE), perchloroethene (PCE), and cis-dichloroethene (cDCE) (Figure 2). Remediation of the contaminated groundwater using conventional pump-and-treat methods can be difficult, costly, and inefficient. The U.S. Navy Engineering Field Activity (EFA) West and NFESC began investigating alternative technologies that have potential technical and cost advantages over pump-and-treat systems. The U.S. Environmental Protection Agency (EPA) has identified PRBs as an emerging technology for groundwater cleanup and suggests that PRBs may be used at 10 to 20% of the chlorinated solvent impacted sites nationwide. A demonstration project to evaluate performance and cost-effectiveness of the PRB technology was initiated by NFESC in partnership with EFAWest in April 1996 under the sponsorship of the Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP).

Site/Location:
Former NAS Moffett Field
Mountain View, California

Site Description:
Chlorinated solvent plume
5,000′ wide X 10,000′ long

POCs:
NFESC
(805) 982-4991
EFAWest
(650) 244-2563

Project Websites:
www.nfesc.navy.mil
www.estcp.org
www.rtdf.org
www.sso.org/ecos/itrc

Contractors:
Battelle Memorial Institute
Tetra Tech EMI

Technology Description

PRB is a passive *in-situ* treatment technology that uses natural groundwater flow conditions of a site for remediation. Methods of installation include constructing a trench across the contaminated groundwater flow path by using either a funnel-and-gate system or a continuous reactive barrier. The gate or reactive cell portion is filled with a treatment media of typically zero-valent granular iron, which is derived from treated scrap metal to remove its valence electrons. The iron filings react with the target contaminants in a strong reducing reaction to form non-toxic, easily biodegradable, by-products, such as ferrous iron, chloride, hydroxide ions, and light hydrocarbon C2-C5 compounds (ethanes, ethenes, etc.). Several variations of PRB configurations are possible, including the more commonly used funnel-and-gate systems, which combine one or more permeable gate and impermeable funnel sections to capture wider contaminant plumes. Continuous reactive barriers may be beneficial when the plume width is smaller and/or contaminant concentrations are lower. Pea gravel sections can also be installed bordering the reactive cell to facilitate uniform flow of contaminated groundwater through the iron cell. The design process begins with collecting contaminated groundwater from the site and then performing a bench scale treatability study to determine the reaction characteristics. The treatability results, along with the aquifer properties (flow velocities, etc.) and computer modeling, are used to determine the required residence time and reactive cell dimensions. Various construction methods can be used to install the PRBs, such as trenching, caisson deployment, mandrels, clamshell digging, soil mixing, or high pressure jetting. The PRB technology has been approved and endorsed by the U.S. EPA, the Interstate Technology and Regulatory Cooperation (ITRC), Department of Energy (DoE), and DoD.

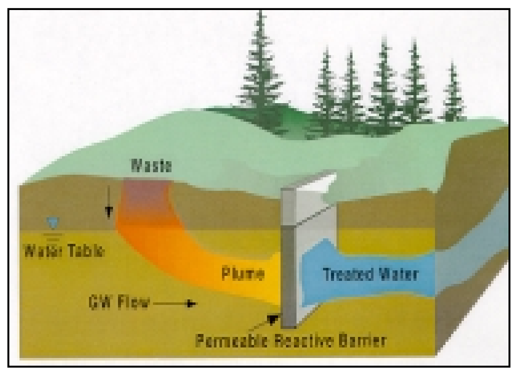

Figure 1. PRB diagram (EPA, 1998).

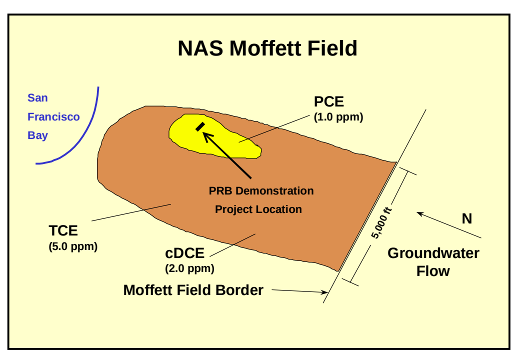

Figure 2. Solvent plume.

Advantages of Technology

- Passive *in-situ* detoxification of groundwater uses no external energy source.
- Potential to treat chlorinated hydrocarbons to very low or non-detect levels.
- Ground surface can be restored to its original land use activity.
- Long-term unattended operation, more cost effective than pump-and-treat systems.

Disadvantages of Technology

- Unknown long-term effects from chemical and/or biological precipitate formation.
- Construction complications from subsurface utilities and/or aboveground structures.
- Limited to depths of less than 50 feet using current construction technologies.

Project Summary

The following tasks were conducted from April 1996 through December 1998:

- Installed a pilot-scale PRB at Moffett Field using a funnel-and-gate design (Figure 3). A backhoe was used to excavate the trench. Steel sheet piles with interlocking joints were used to form the funnel and the sides of the gate. Iron filings, pea gravel, and 48 multi-level monitoring wells were then placed into the excavated gate (Figure 4). Twenty-one aquifer wells were also used to monitor the performance of the PRB. The ground surface was re-paved for its continued use as a parking lot (Figure 5).
- Six consecutive quarterly groundwater sampling events were conducted for targeted constituents, including organic, inorganic, microbiological, and reaction by-products from the monitoring wells located in the gate and surrounding aquifer areas.
- Field measurements were performed during the performance monitoring and evaluation period to evaluate the hydraulic flow, capture efficiency, and monitor reactivity characteristics (water levels, groundwater flow/velocity measurements, slug tests, bromide tracer testing, and iron cell coring analyses) of the PRB.

Figure 3. Funnel and gate system.

Moffett Field Demonstration Results

The PRB system at Moffett Field has been successfully treating chlorinated solvent contaminated groundwater since April 1996:

- Sampling results indicate that the PRB is reducing the influent concentrations of TCE (2,900 micrograms/liter [ug/L]), cDCE (280 ug/L), and PCE (26 ug/L) to below MCLs and/or non-detectable limits within the first few feet of the iron cell (Figure 6).
- Vinyl chloride (4 ug/l) was not present in the upgradient aquifer. It was created as a reduction reaction degradation by-product, and was then cleaned up in the iron cell.
- Organic by-products, primarily methane, ethane, and ethene, were found to be present in the iron cell. The dissolved gases rapidly dissipated in the downgradient aquifer.
- Actual flow capture of the funnel-and-gate system was similar to model predictions.
- Flow-meter/tracer tests indicated forward flow through the iron cell at ½ to 1 ft/day.
- Iron cell coring sample results showed minimal short-term effects from chemical precipitation. However, the coring samples did detect the initial stages of inorganic precipitation of calcium and magnesium carbonate, iron-sulfide, and hydroxide compounds. Geochemical modeling also suggests that changes can occur in the inorganic chemistry from precipitate formation, which is a long-term concern for the potential loss of reactivity and permeability in the iron cell.

Figure 4. Reactive cell (gate).

Economic Benefits

The PRB at Moffett Field has not required any operation and maintenance (O&M) since its construction, and the only recurring costs would be for compliance monitoring. It is possible that the iron filings may need maintenance or replacement every 10 to 20 years. To obtain some perspective on the economic benefits of the PRB, the cost of the barrier was compared to the costs of the pump-and-treat option. The PRB requires a higher initial capital investment, however, over the long term, the O&M savings accrue and the PRB will break even in approximately 6 to 7 years. More significantly, the cost savings are estimated at $26 million over a 50-year period.

Figure 5. Parking area.

Lessons Learned

- A proficient knowledge and understanding of the site hydrogeology is necessary.
- A competent confining layer is required beneath the PRB to prevent potential contaminant underflow.
- Site specific treatability studies and groundwater modeling are necessary.
- Proper design and construction techniques are key to successful implementation of the PRB. The ITRC has published a design guidance document available to the general public.

EPA, ITRC, DoE, and DoD are sponsoring additional performance and longevity evaluations at multiple PRB sites across the country over the a 3 year period (FY99-01) in an effort to gain widespread regulatory acceptance and remedial project manager confidence in using the PRB technology.

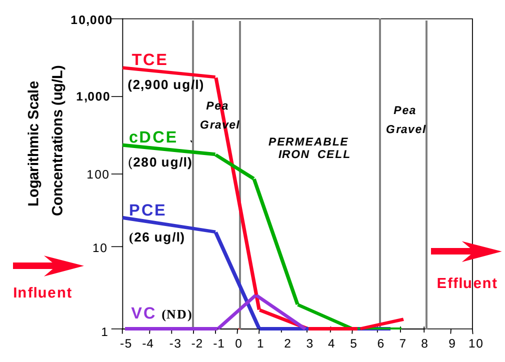

Figure 6. Target contaminants.